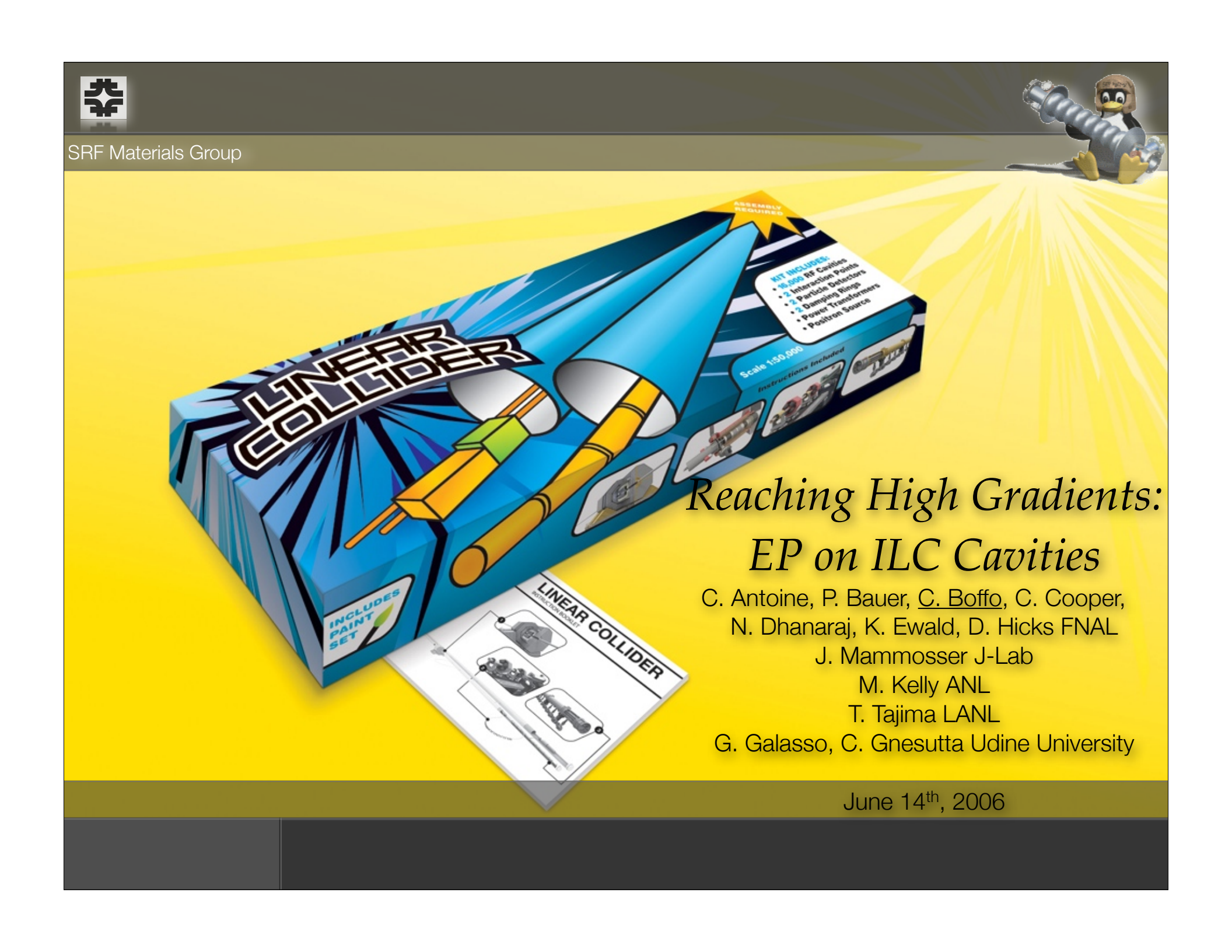
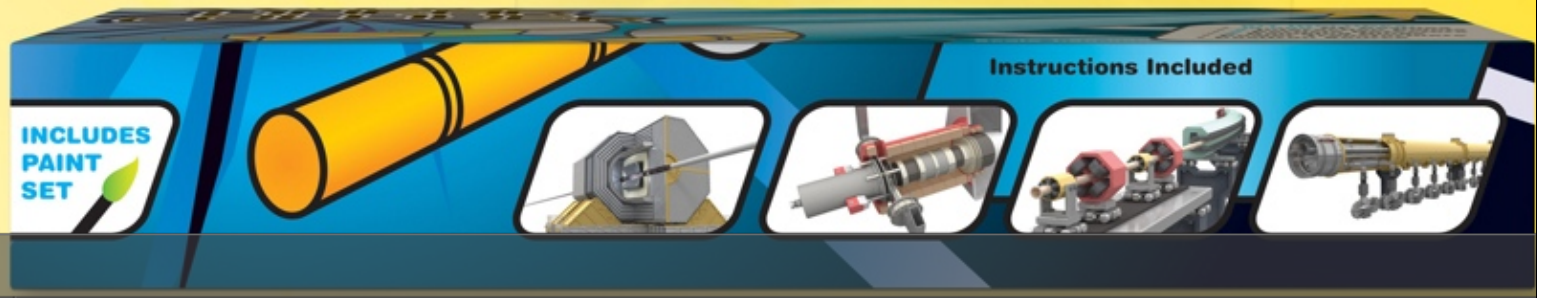

SRF Materials Group
LINEAR COLLIDER
ASSEMBLY REQUIRED
KIT INCLUDES:
• 16,000 RF Cavities
• 2 Interaction Points
• 2 Particle Detectors
• 2 Damping Rings
• 2 Power Transformers
• Positron Source
Scale 1:50,000
Instructions Included
INCLUDES PAINT SET
LINEAR COLLIDER
INSTRUCTION BOOKLET
Reaching High Gradients:
EP on ILC Cavities
C. Antoine, P. Bauer, C. Boffo, C. Cooper,
N. Dhanaraj, K. Ewald, D. Hicks FNAL
J. Mammosser J-Lab
M. Kelly ANL
T. Tajima LANL
G. Galasso, C. Gnesutta Udine University
June 14th, 2006

# Outline



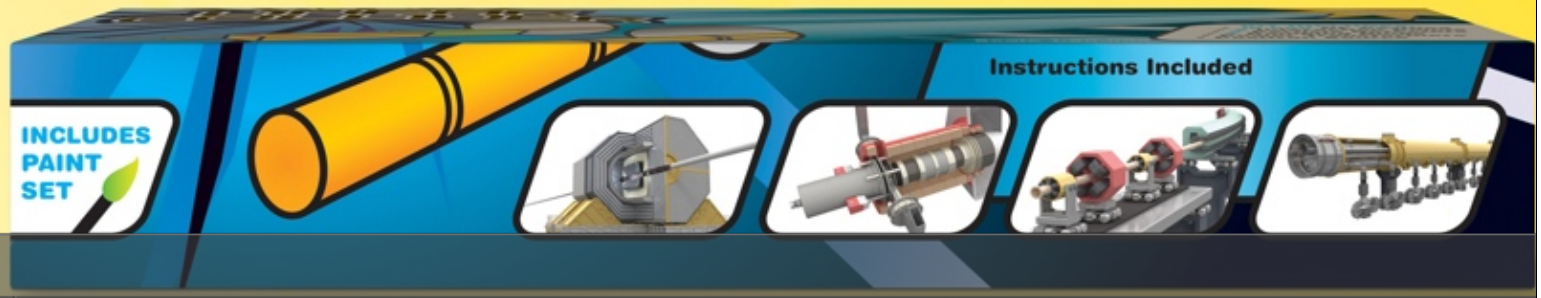
- Cavity Processing
- EP, BCP and CBP
- EP R&D on small samples
- EP R&D 1-cell setup
- Simulations
- EP Facility
- Connection with industry
- CBP R&D
- Conclusions



# Cavity Processing



- Processing of the cavity is a necessary step for many reasons:
  - The first etching removes the layer of niobium contaminated and mechanically work hardened during the forming
  - The heat treatments removes hydrogen and partially anneals the material
  - The second etching removes the superficial layer of niobium after the heat treatment
  - The low temperature bake recovers the Q-drop
  - The High Pressure Rinse eliminates effectively all particles form the surface of the cavity before it is sealed

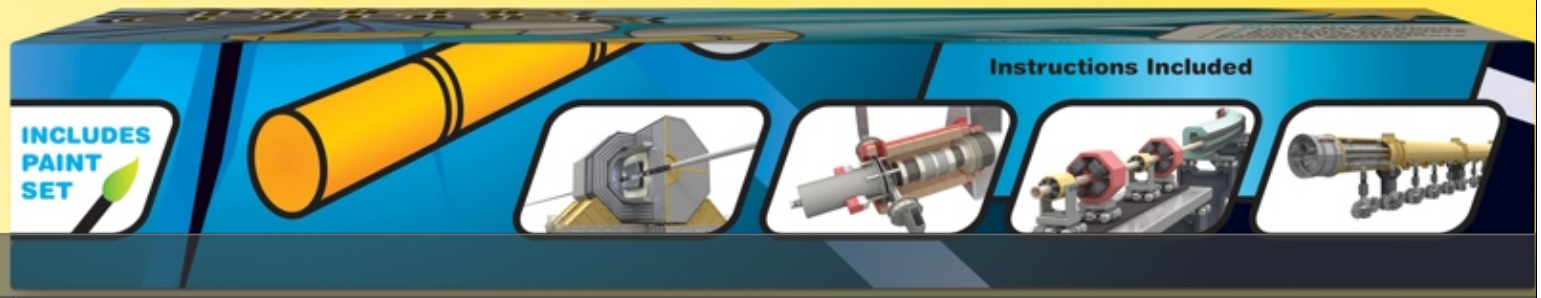


# Material removal



- The chemical or mechanical removal of material from the cavity surface is performed at several steps of the fabrication procedure and during processing:
  - BCP is applied before welding 2 parts together and could be the standard material removal technique for large grain or single crystal material
  - EP is the standard removal technique for polycrystalline material
  - CBP is an alternative method that does not need acids and could substitute the initial heavy EP

**BCP** Buffer Chemical Polishing **EP** Electro-Polishing **CBP** Centrifugal Barrel Polishing



# BCP EP CBP

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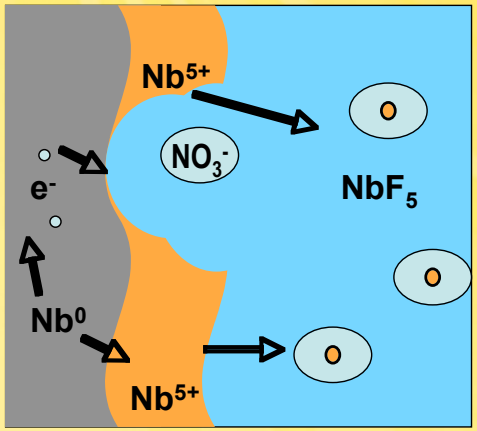
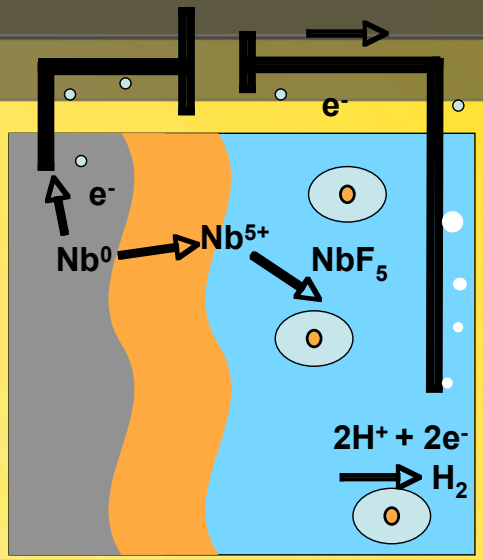
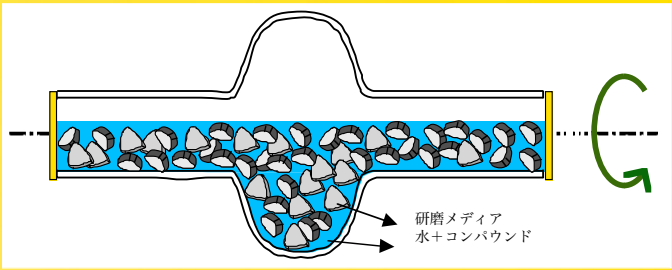



$6\ Nb + 10\ HNO_3 \rightarrow 3\ Nb_2O_5 + 10\ NO\uparrow + 5\ H_2O$

$Nb_2O_5 + 10\ HF \Leftrightarrow 2\ NbF_5 + 5\ H_2O$

## BCP

1:1:2 HF $HNO_3$ $H_3PO_4$

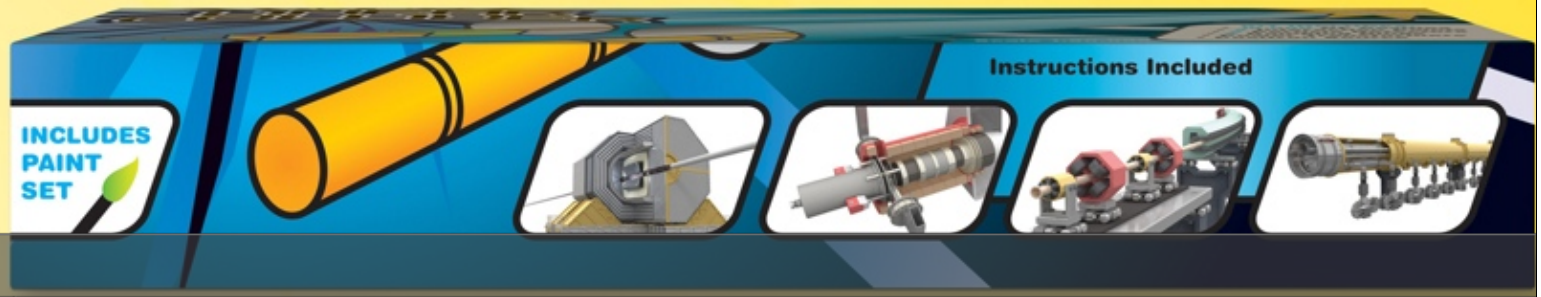
$Nb \rightarrow Nb^{5+} + 5\ e^- \rightarrow Nb_2O_5$

$Nb_2O_5 + 10\ HF \Leftrightarrow 2\ NbF_5 + 5\ H_2O$

## EP

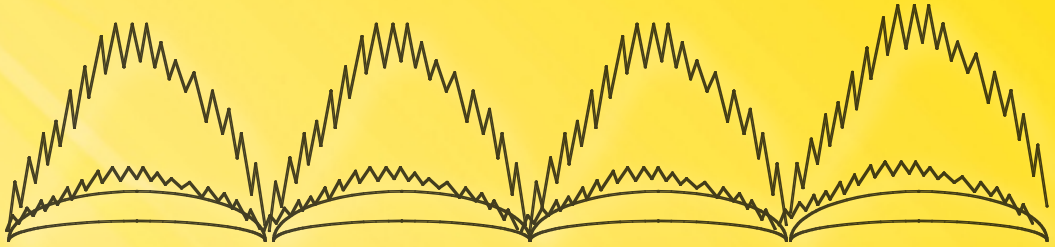
10:1 $H_2SO_4$ HF

## CBP

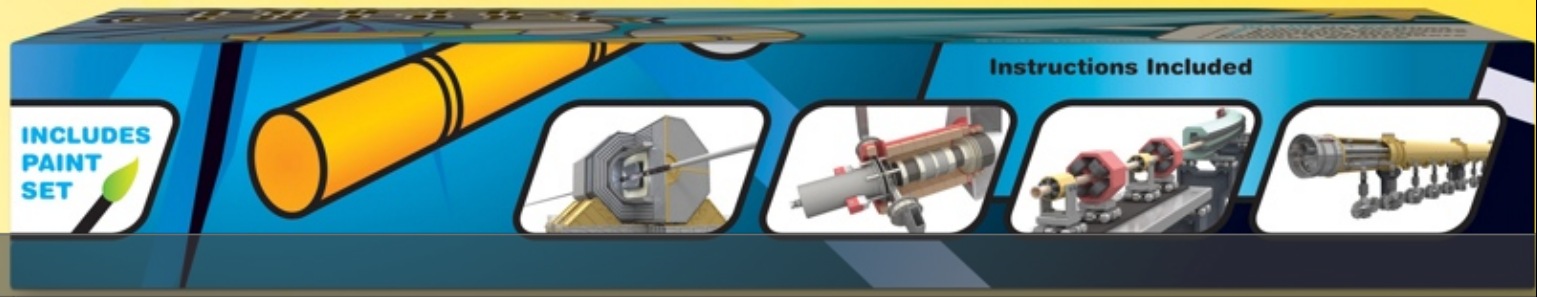


# EP Principle





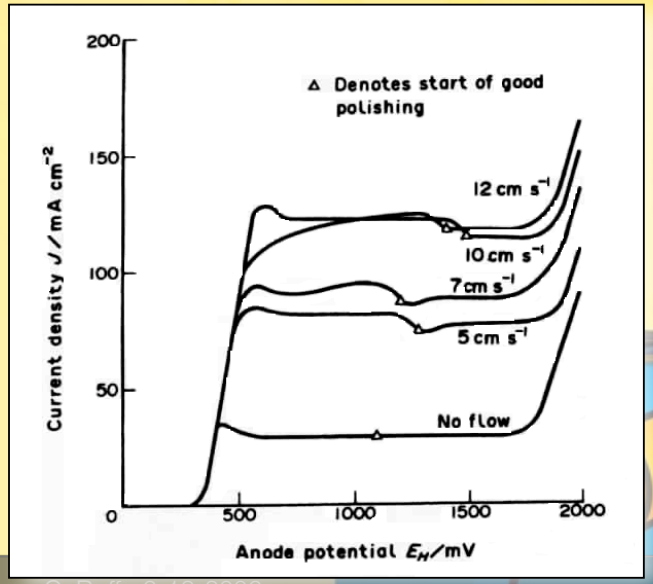
- EP is the combination of Macropolishing and Micropolishing
  - Macropolishing affects defects of 1um or bigger and its origin is related to the presence of the viscous layer
  - Micropolishing or brightening affects defects of 0.1 um or smaller and its origin is connected to several mechanisms taking place at the solid liquid interface
  - Nanopolishing does not apply in this case

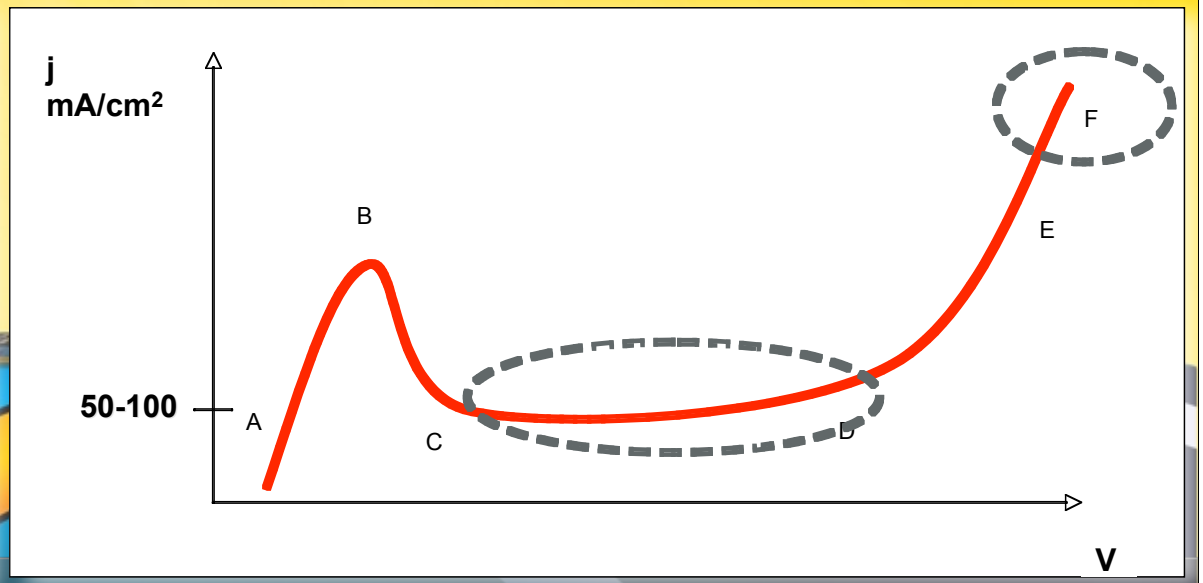


# EP I-V curve



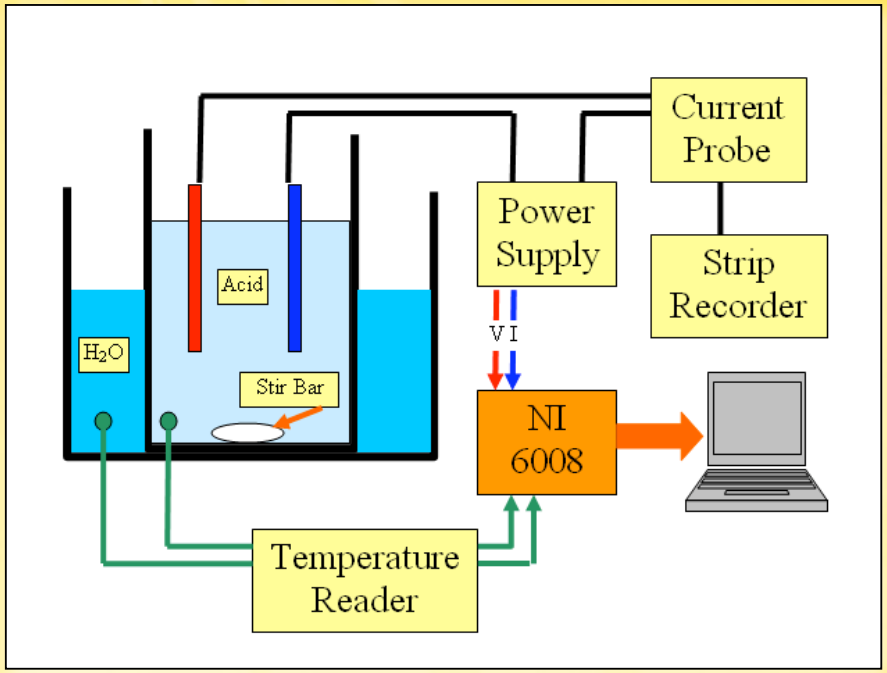
- Typical I-V curve of electropolishing:
  - A-B active dissolution
  - B-C unstable area
  - C-D Plateau -> Polishing
  - D-E Slow Oxygen evolution -> Pitting
  - E-F Fast Oxygen evolution -> Polishing by Pitting



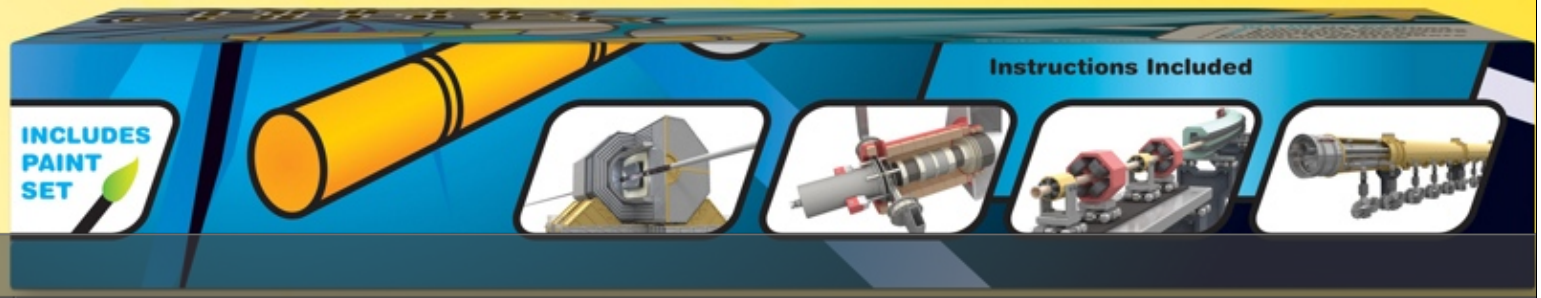



# EP Basic Parameters



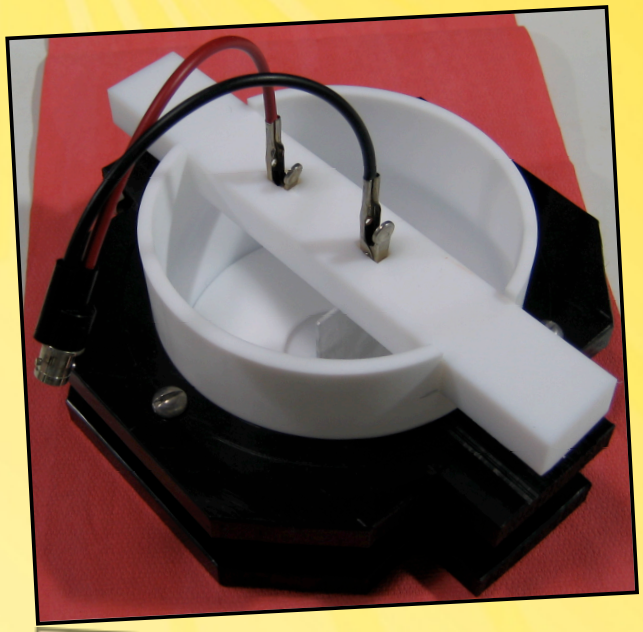



| Parameter | Unit | Value |
|---|---|---|
| Voltage | V | 12-17 |
| Current Density | $mA/cm^2$ | 30-100 |
| Temperature | C | 25-35 |
| Temperature stability | C | +/- 1 |
| Acid flow | - | steering |



# EP Small Samples

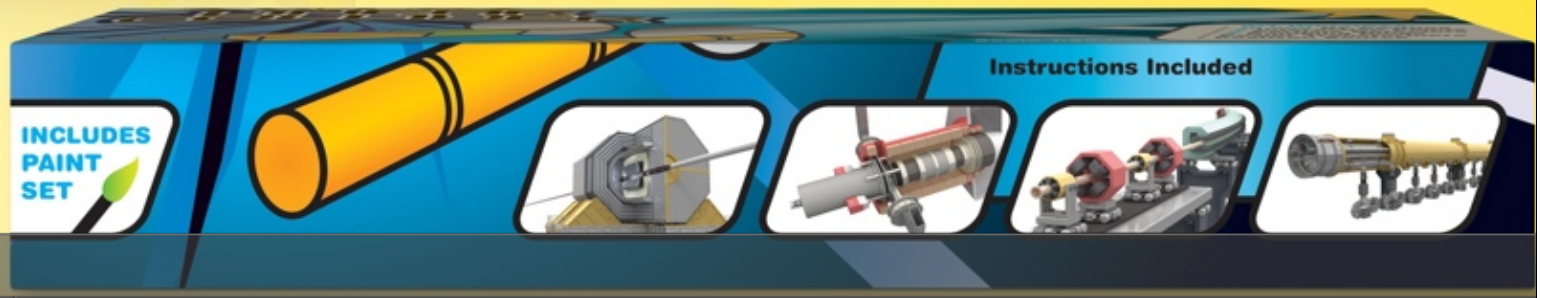




- Simple geometry
- Small amount of acid
- Good temperature control
- Fast turn around
- "Easy" to model

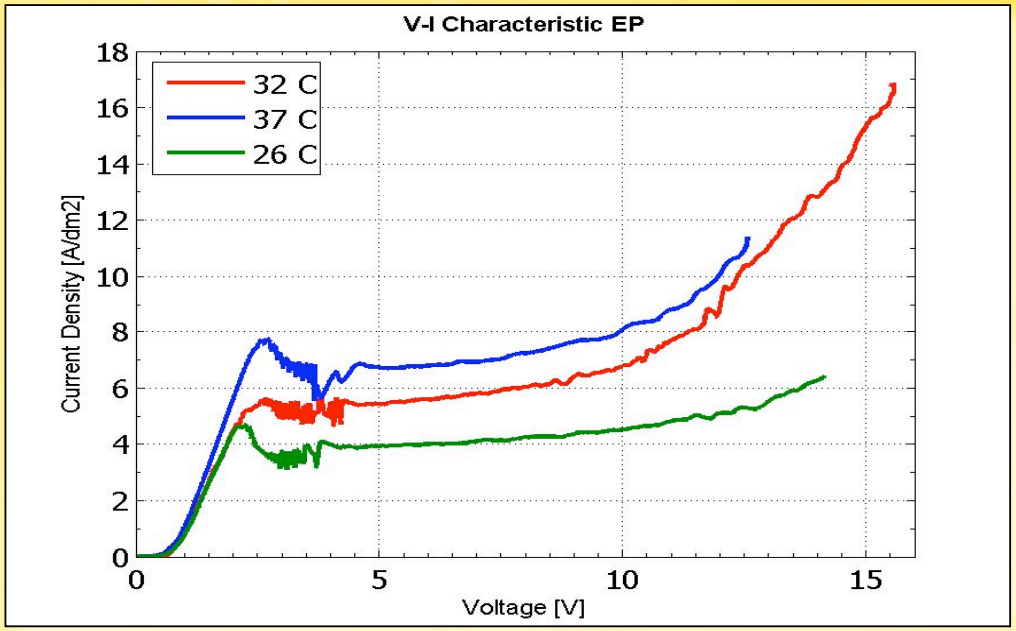
**BUT:**

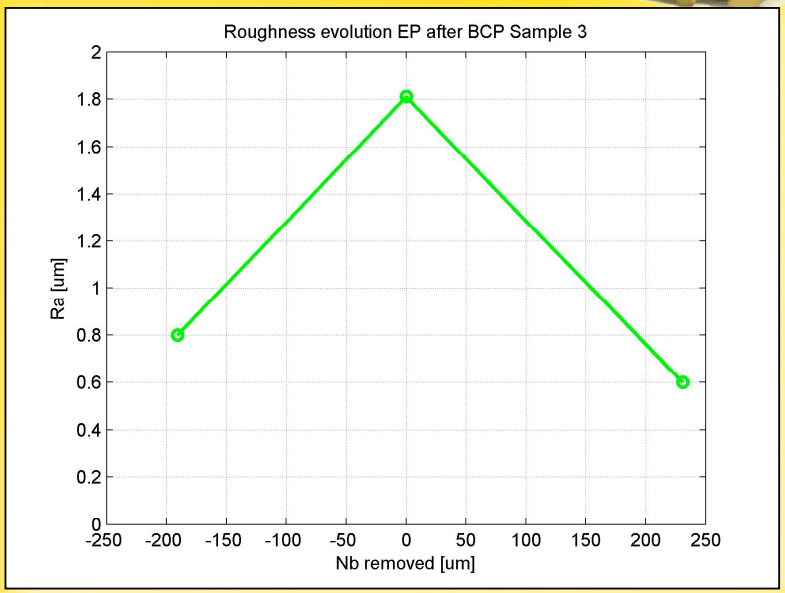
- Not completely representative of the cavity setup

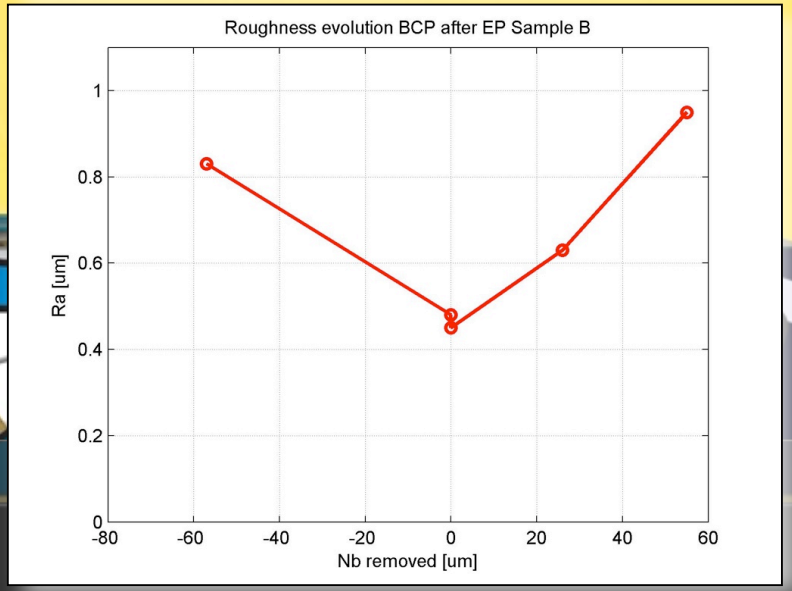


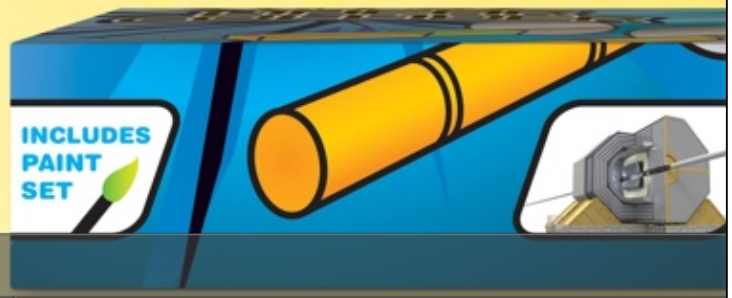
# EP Small Samples

SRF Materials Group



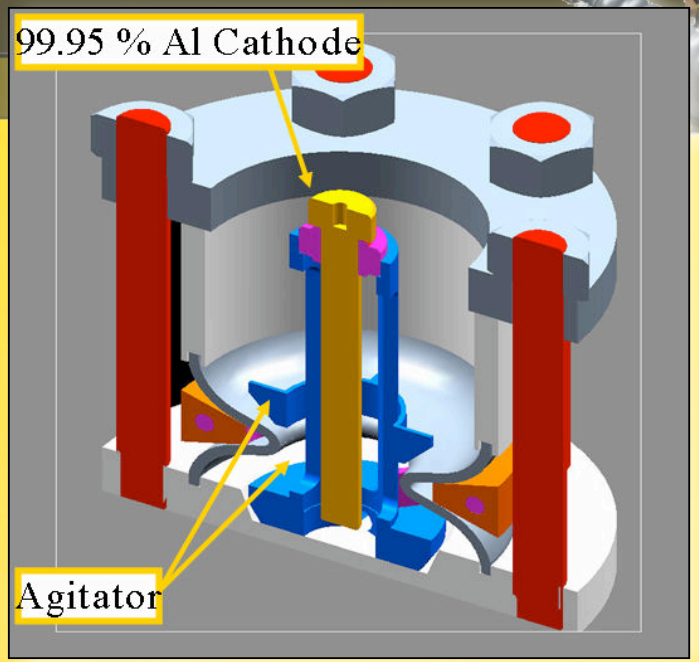



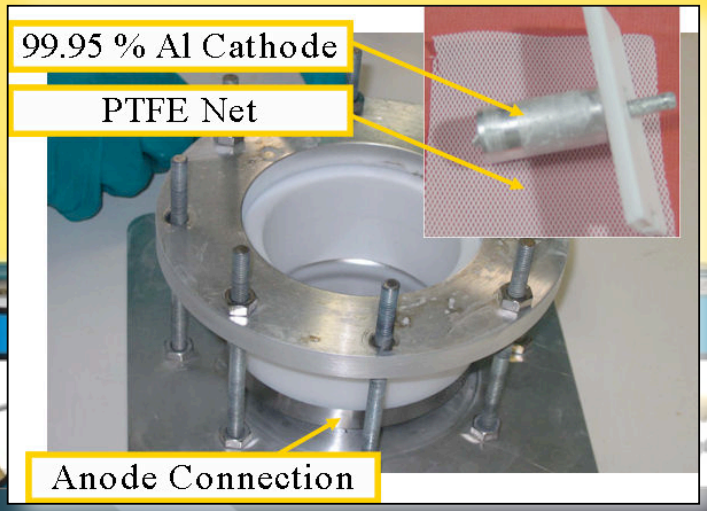



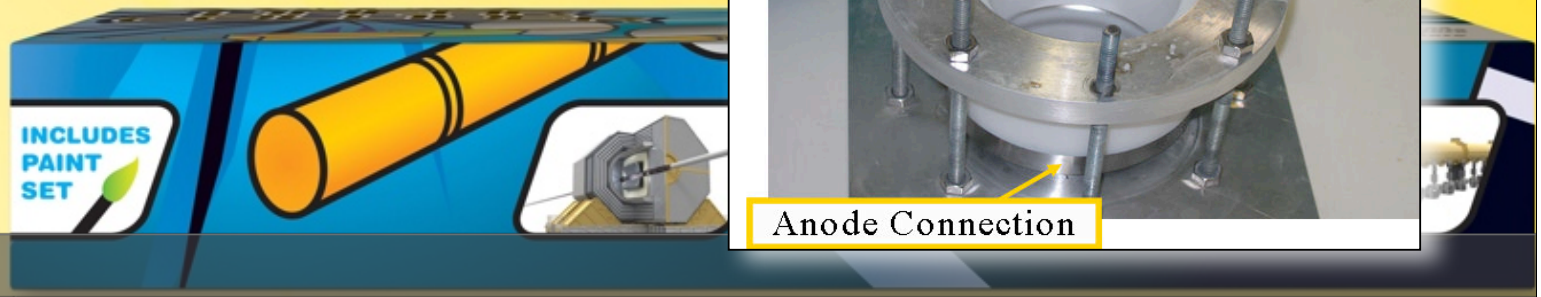
# EP Small Samples



- Half cell or dumb-bell setups can help understanding better:
  - the differential removal rate in vertical condition
  - The effect of steering speed
  - The effect of cathode dimension and shape

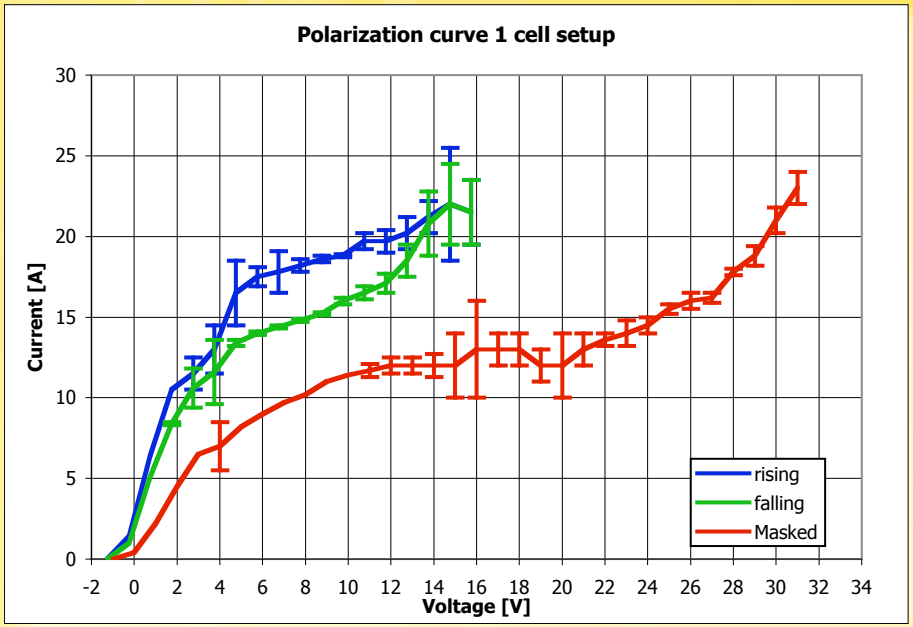


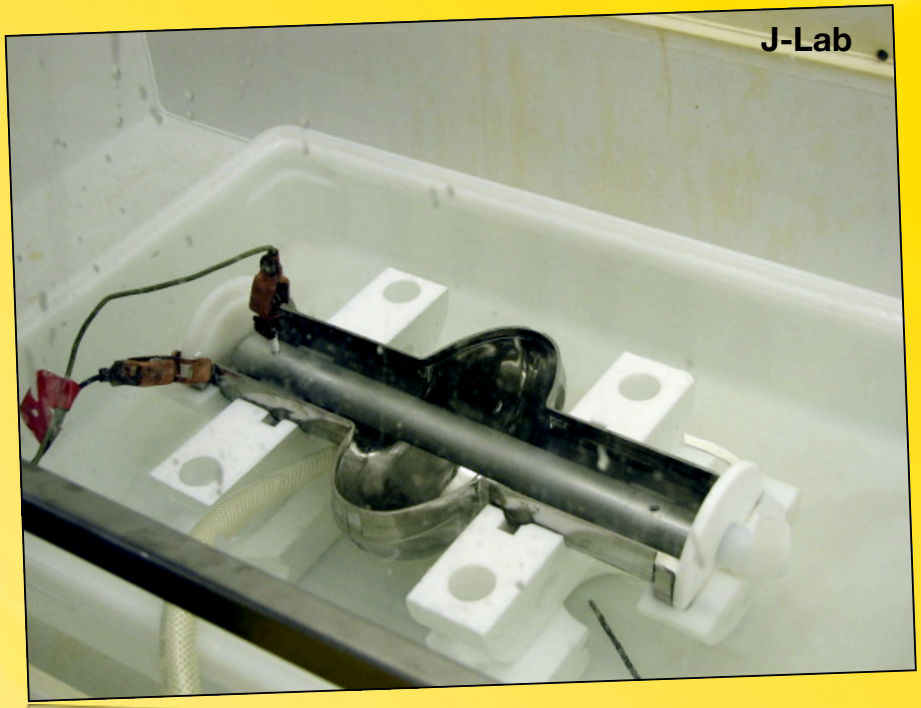



# EP Small Samples

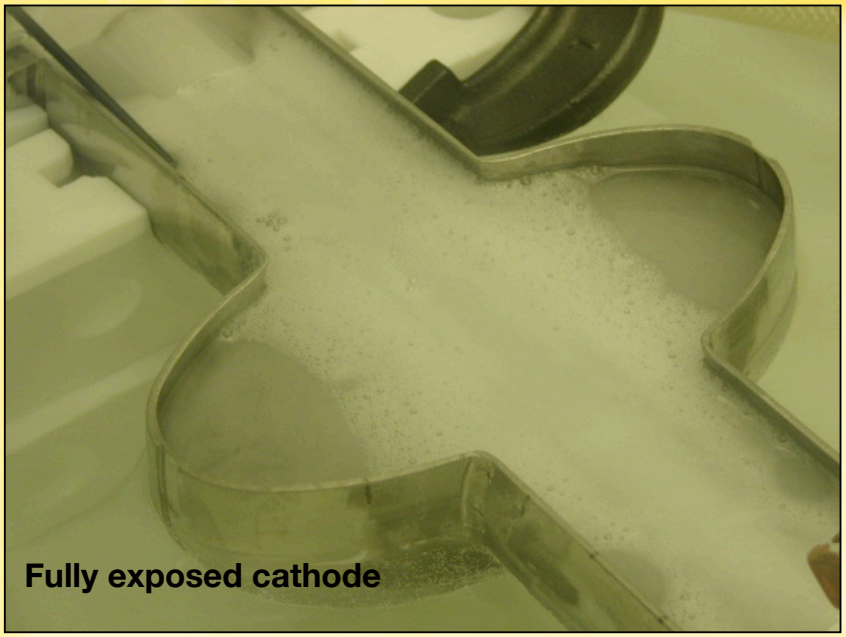
SRF Materials Group



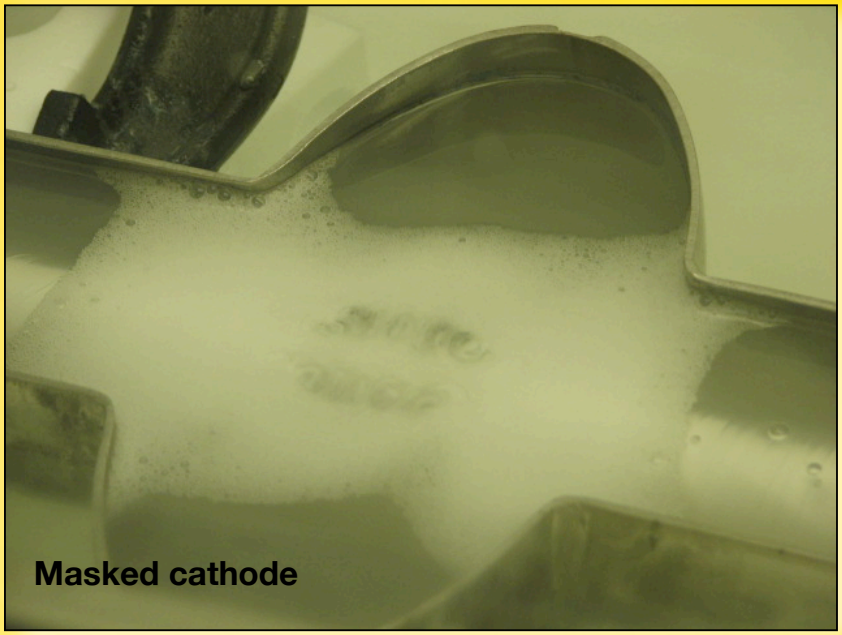




# EP Small Samples

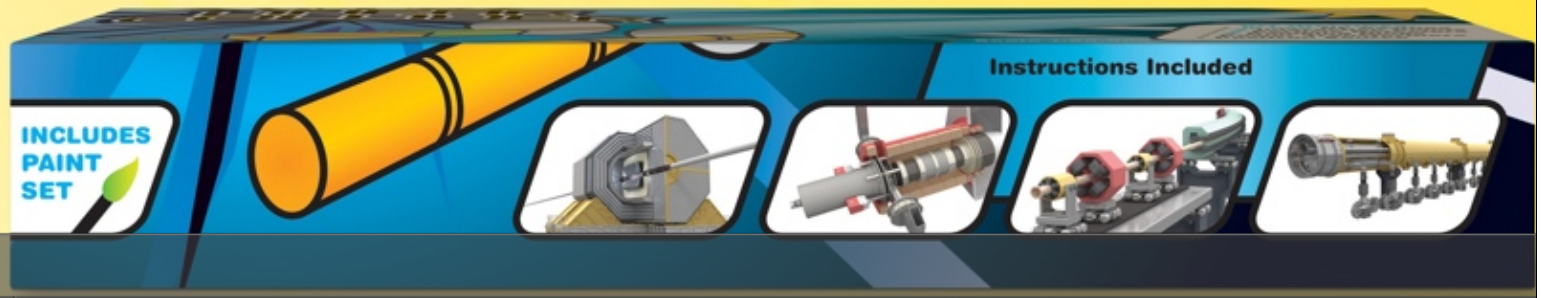
SRF Materials Group



Fully exposed cathode



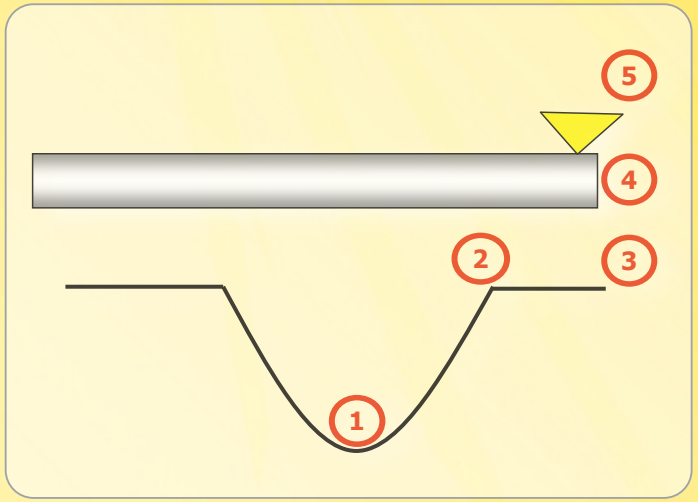
Masked cathode



# EP Small Samples



- Masking the cathode at the iris is a common practice during EP of 9-cell cavities to reduce the differential removal rate between iris and equator, but this small experiment show that it can have a strong effect on the electrochemical cell resistance.

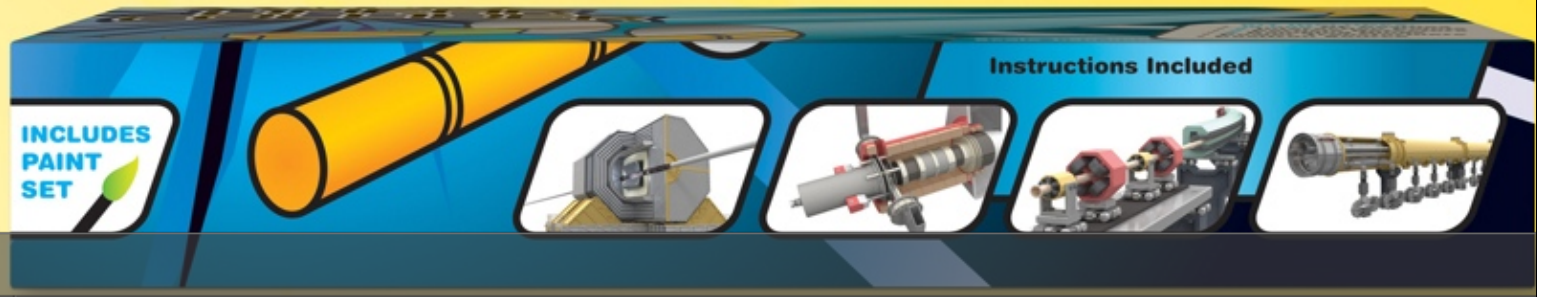



naked cathode

| PS V | Current A | Temperature C | 1 V | 2 V | 3 V | 4 V | 5 V |
|---|---|---|---|---|---|---|---|
| 16 | 16.2 | 23.3 | 12.5 | 13.5 | 13.2 | 14.25 | 15.5 |
| 19 | 30.7 | 24.5 | 14.5 | 15.4 | 15 | 15.8 | 17.8 |
| 3 | 10.4 | 24.1 | 0.6 | 0.8 | 0.7 | 1.43 | 3 |

masked cathode

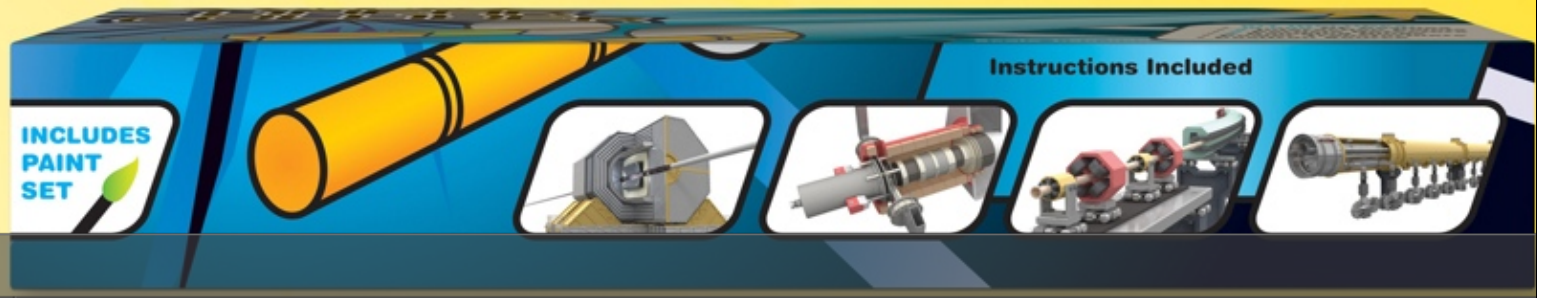
| PS V | Current A | Temperature C | 1 V | 2 V | 3 V | 4 V | 5 V |
|---|---|---|---|---|---|---|---|
| 16 | 22 | 29.8 | 10 | 6.9 | 1 | 14.3 | 15.3 |
| 19 | 20.8 | 30 | 13.2 | 10.2 | 2.4 | 17.4 | 18.4 |
| 3 | 5.4 | 30.8 | 0.65 | 0.55 | 0.35 | 2.2 | 2.73 |



# EP Small Samples - C. Antoine



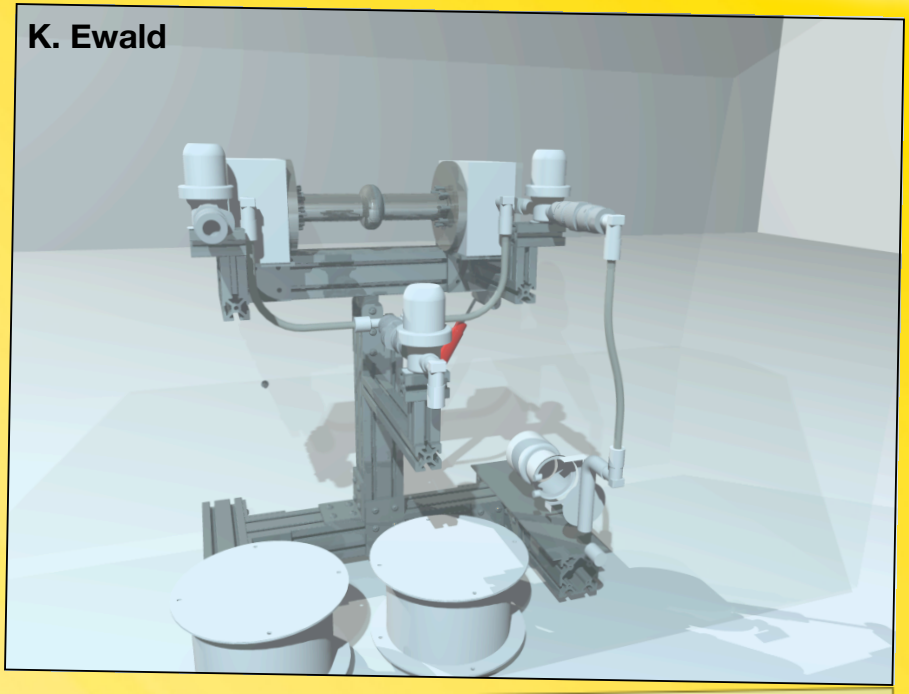
- Several activities can be performed at the small sample level to explore the fundamental characterization of EP:
  - Correlation of degradation to $F^-$ content
  - Online monitoring of $F^-$
  - Alternative viscous buffers
  - Extension of the plateau
  - New acid mixtures
  - Fundamental current limiting factors



# EP 1-cell setup

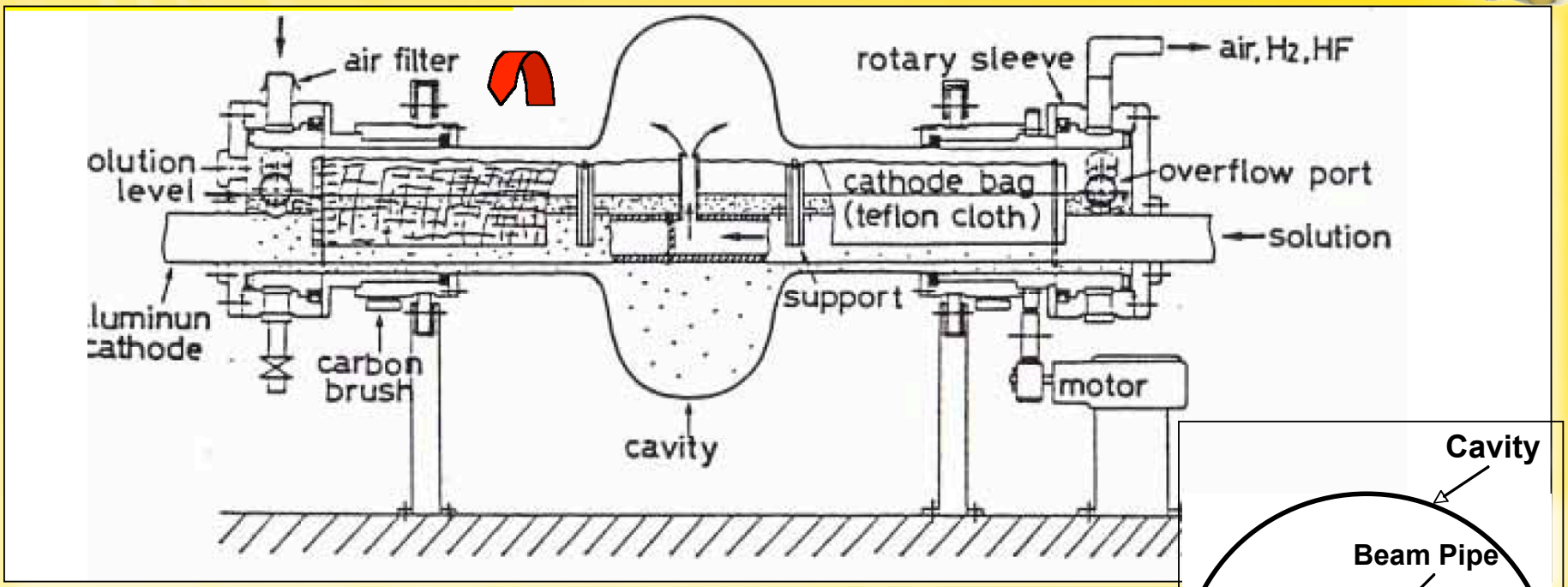


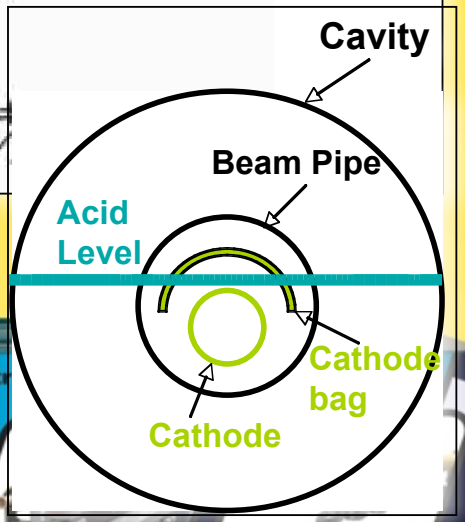
- Will be part of a single cell program
- Allows fast turn around
- Simpler than full facility
- Can be used as test-bed for components to be used in the full facility

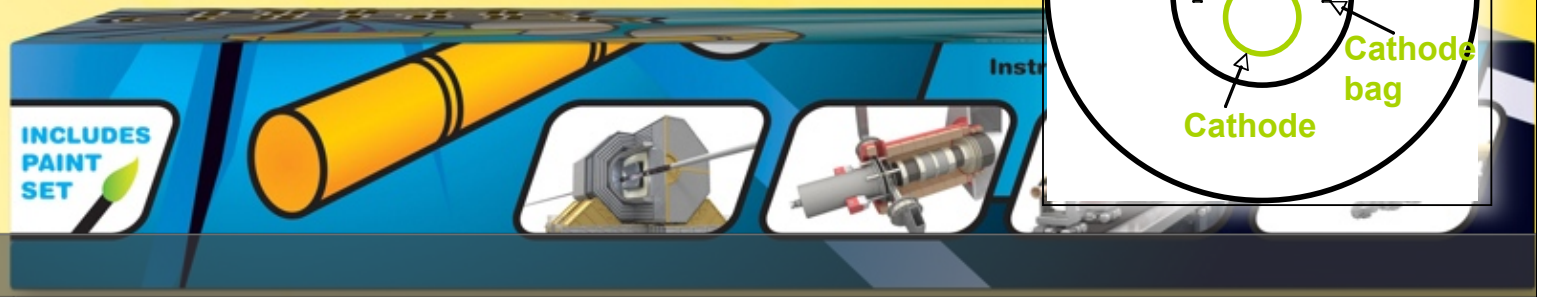



# EP 1-cell setup





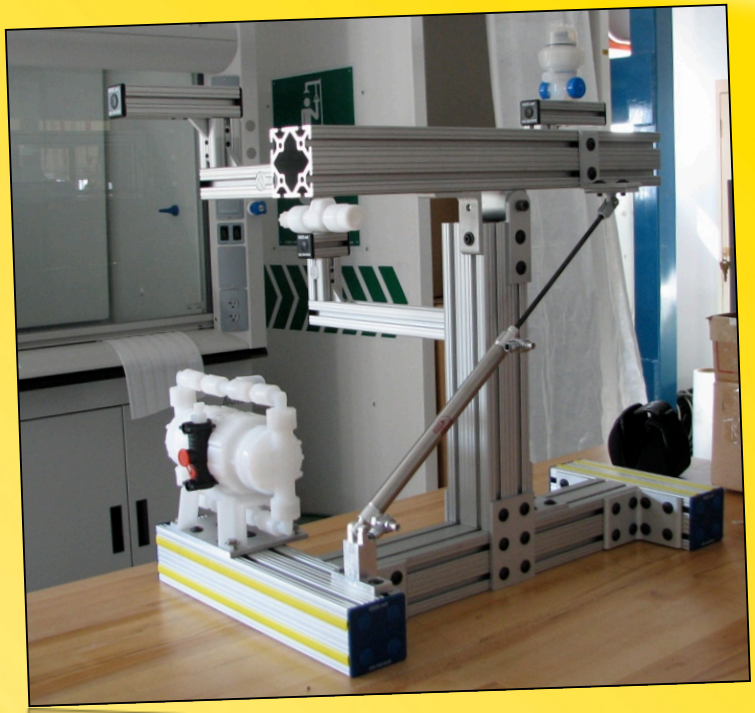



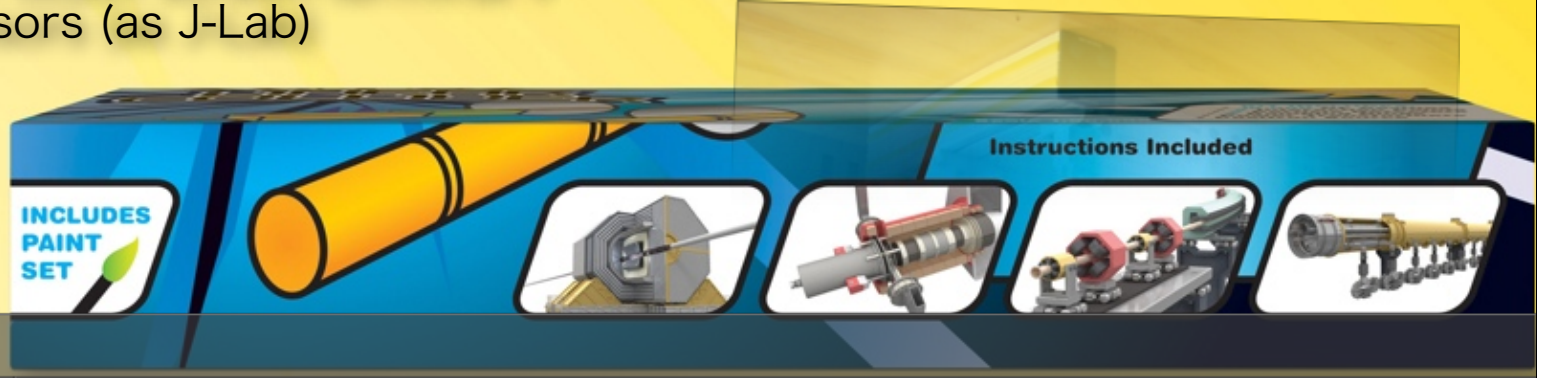



# EP 1-cell setup



- 3.9 GHz to be usable at FNAL (2 liters of acid) in a standard fume hood
- Testing center pivoting
- Testing new valves
- Testing new lip seals
- Testing new quick disconnect system
- testing new end group design
- Testing new PLC based control system with touch screen terminal + wireless sensors (as J-Lab)



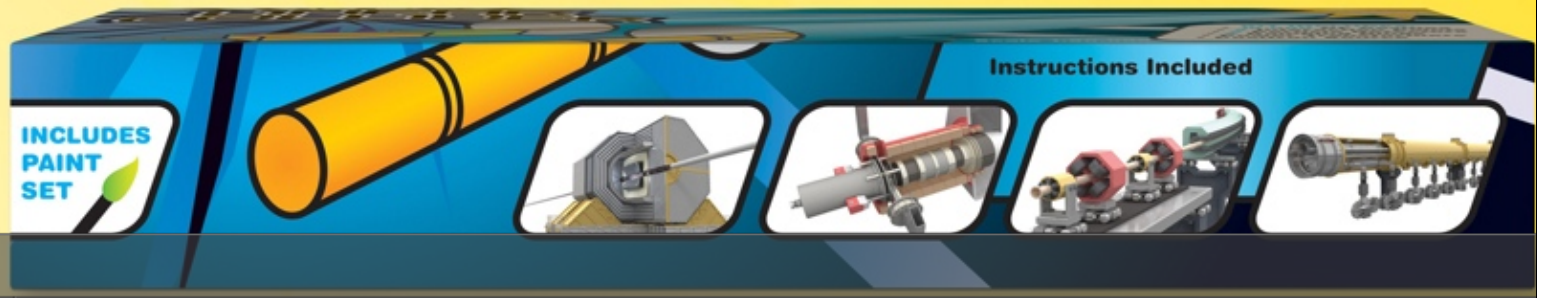


# EP 1-cell setup



- Be operative by mid august 2006
- Fabricating 6 1-cell 3.9 GHz cavities:
  - 3 Wah Chang polycrystal material
  - 2 Cabott polycrystal material
  - 1 CBMM single crystal material
- Integrate within the effort in better understanding EP and optimize the process

| Parameter | Unit | Value |
|---|---|---|
| Voltage | V | 12-17 |
| Current Density | $mA/cm^2$ | 30-100 |
| Temperature | C | 25-35 |
| Temperature stability | C | +/- 1 |
| Acid flow | l/min | 0.1-1 |
| Cavity rotation | rpm | <1 |
| N2 flow | scfm | 0.1 |
| Nb content | g/l | <5 |

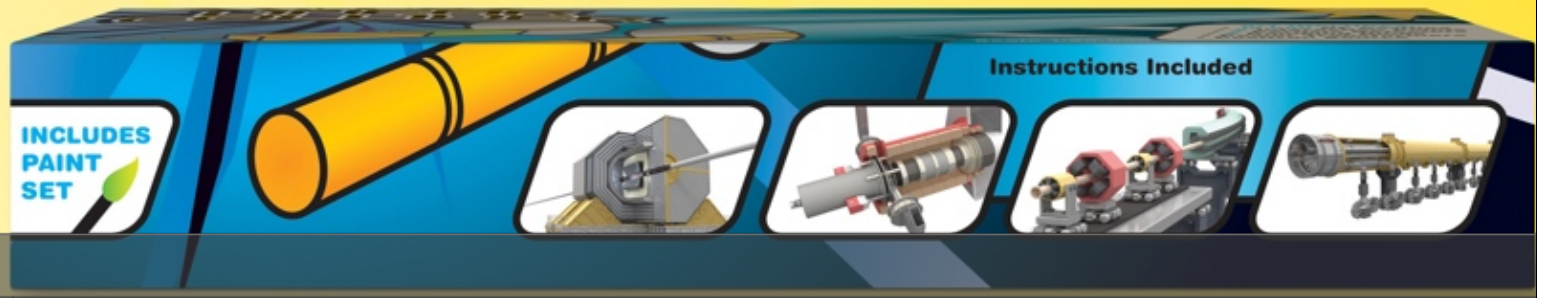


# EP simulation



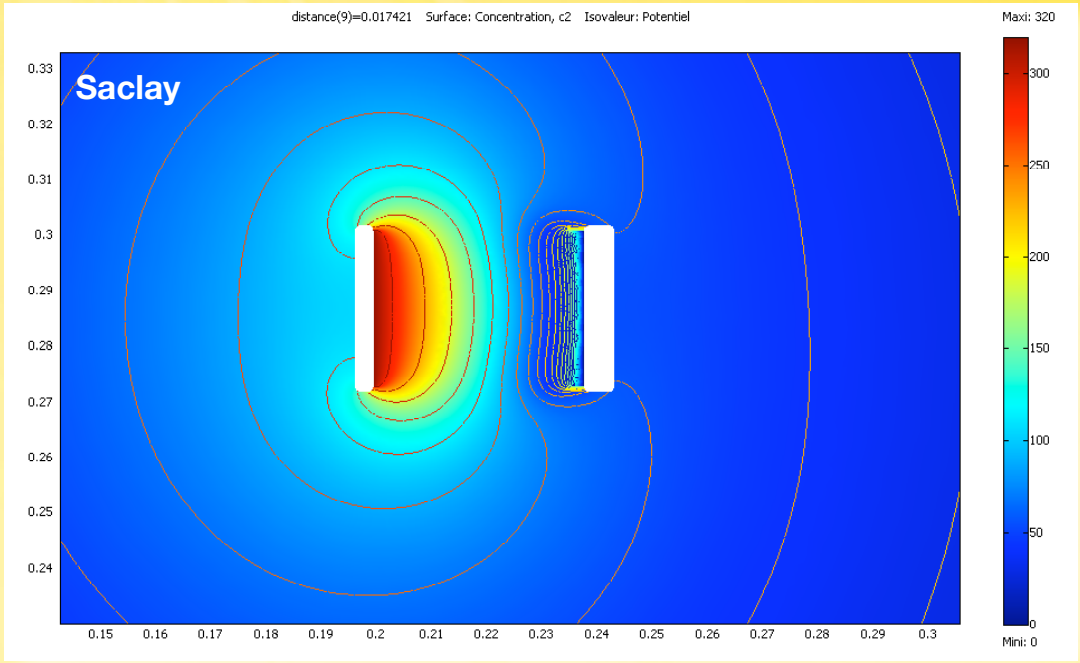
- EP is a complex process that involves:
  - The solution of the Navier-Stokes equations for a complex geometry
  - The solution of the convective and conductive thermal systems
  - The solution of the diffusion equations
  - The electrical characteristic of the process

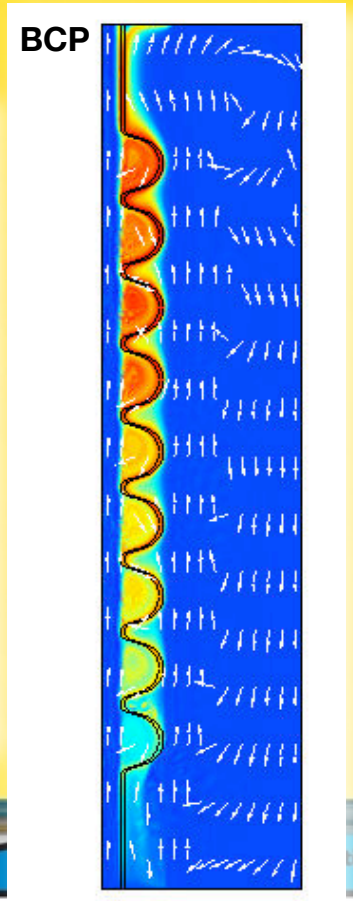
**Solving part of these coupled systems of equations would allow to help mapping the parameter space of the process. Simulation of small samples or half cell setup would be "easier" and still provide a large quantity of information.**

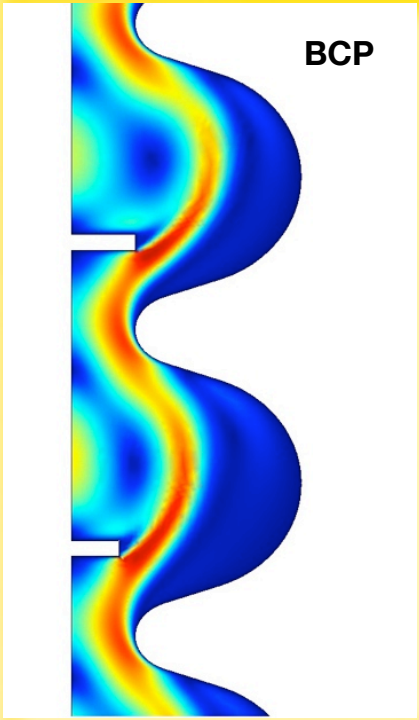


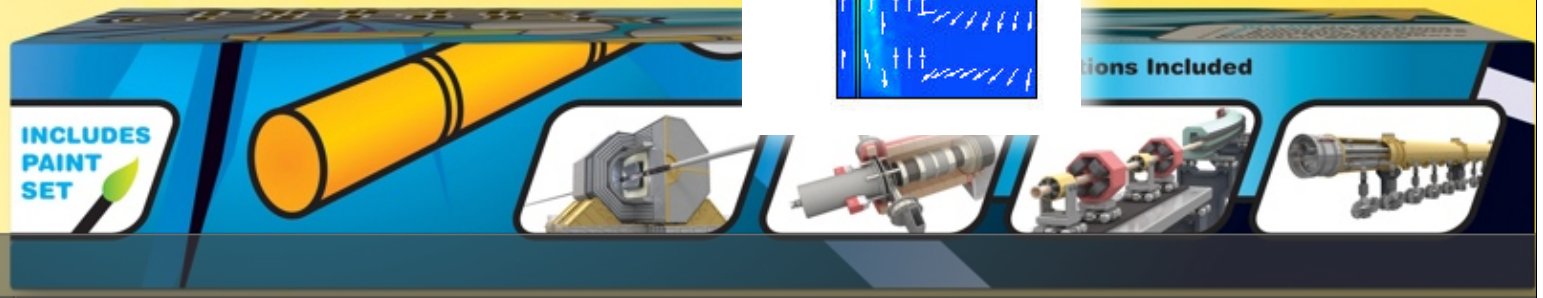
# EP simulation

SRF Materials Group



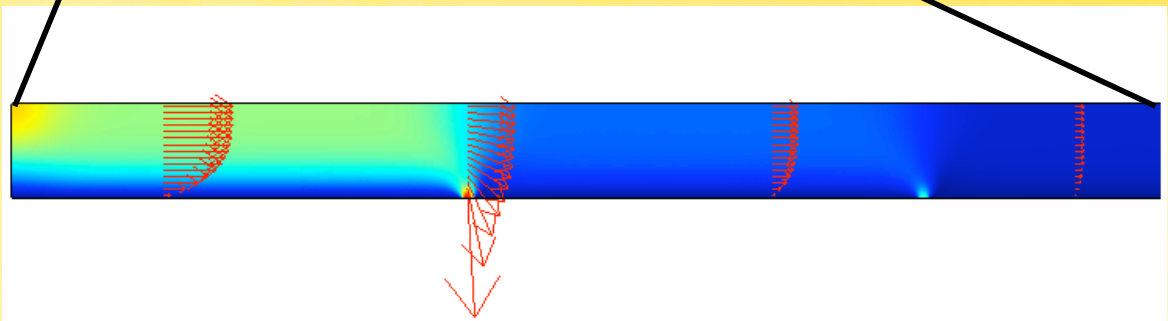



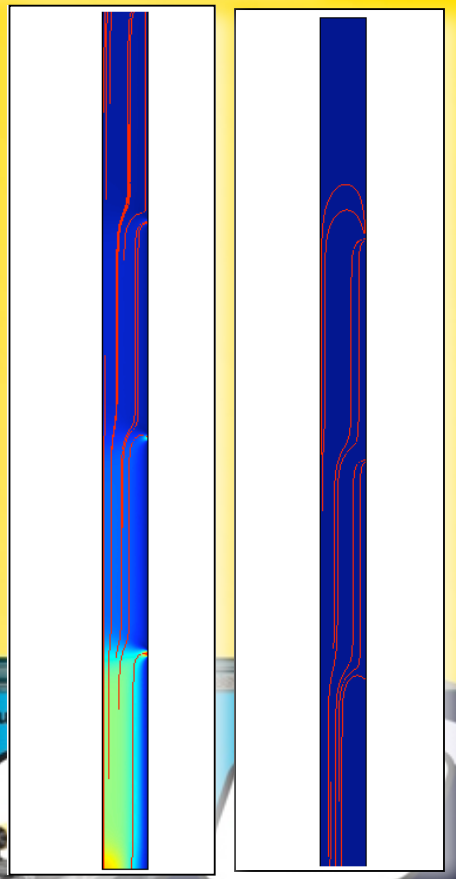



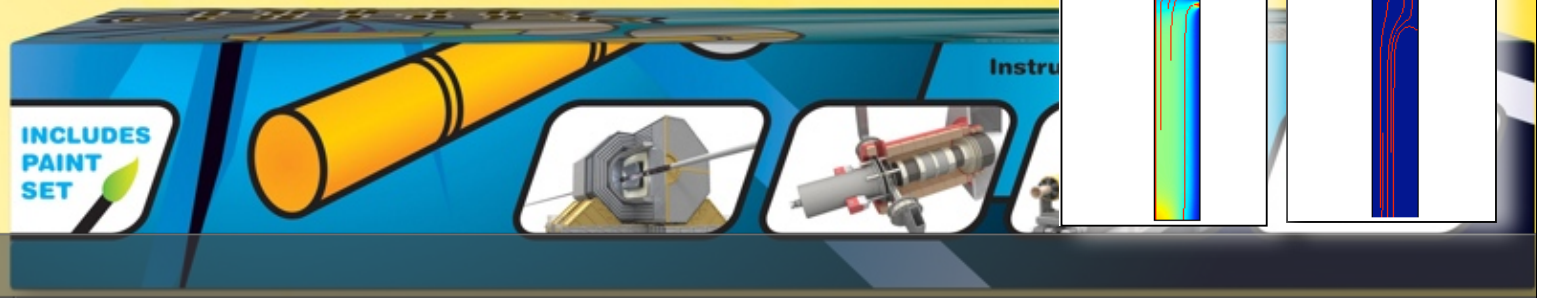
# EP simulation - N. Dhanarag







- Simulation and optimization of the acid flow in the cathode

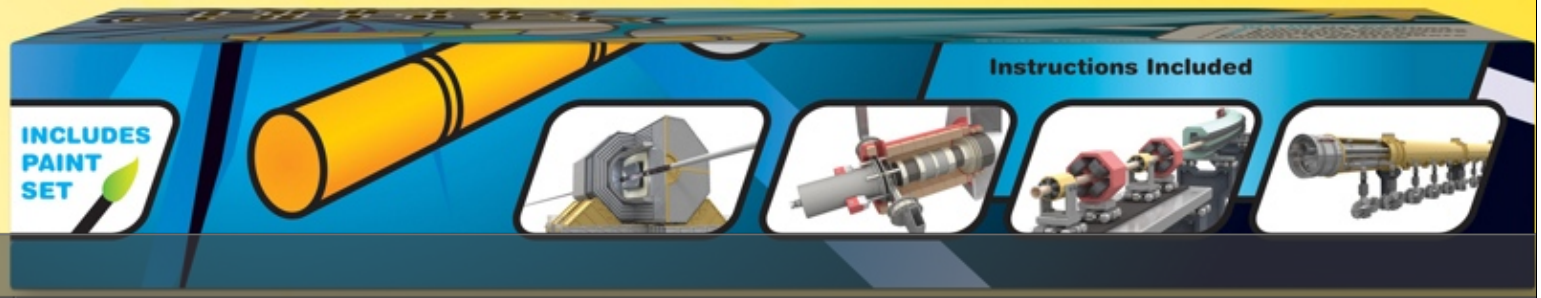


# EP simulation



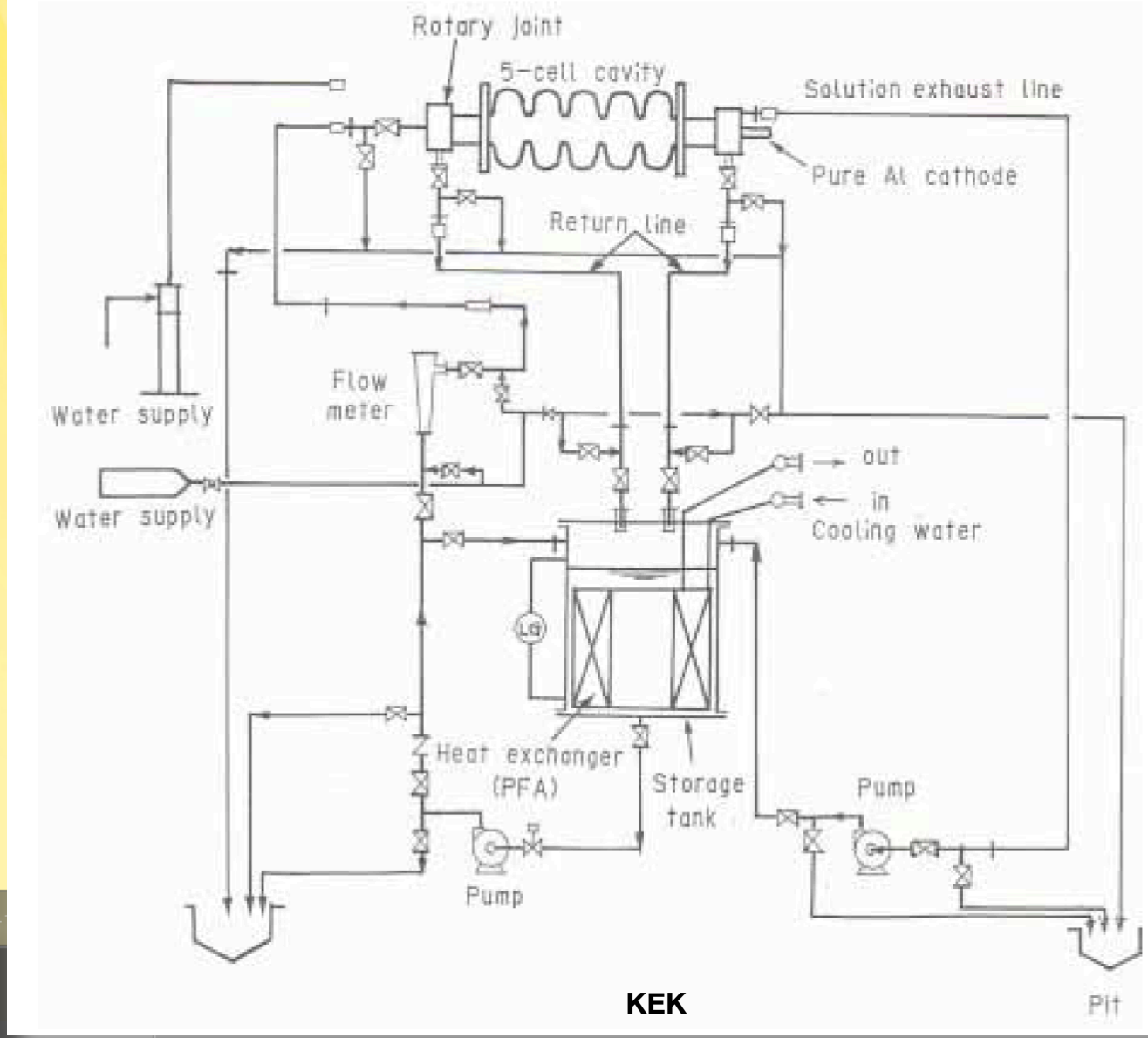
- ☆ Simplified analytical solution of the thermal fluid problem using Poseuille flow in simple and complex geometry to be solved by end of august
- ☆ Numerical solution of the same model + diffusion problem in the next 8 months (Laurea thesis)

**Cristiano Gnesutta - Laurea sudent Udine University**



# EP Facility

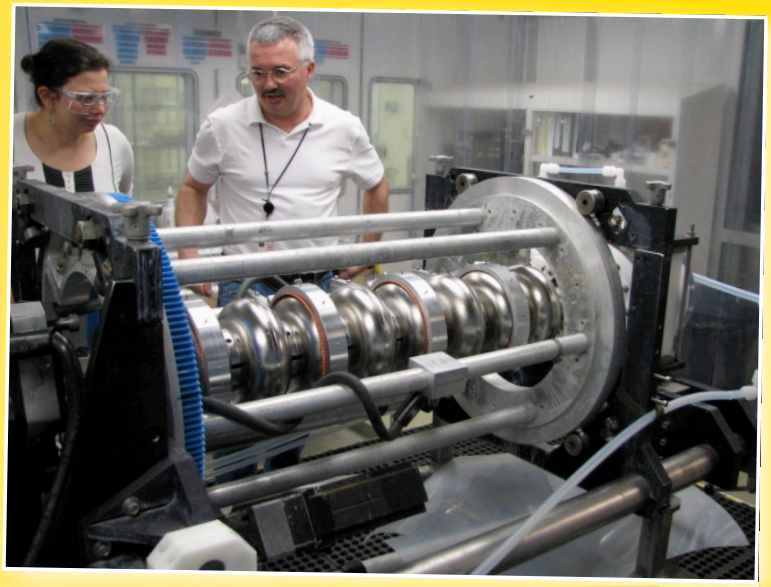
SRF Materials Group



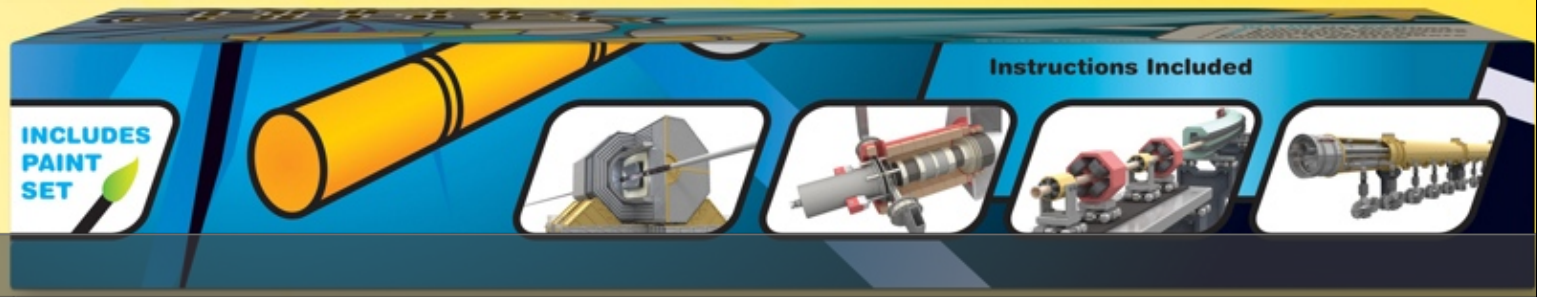

**KEK**

# EP Facility

SRF Materials Group

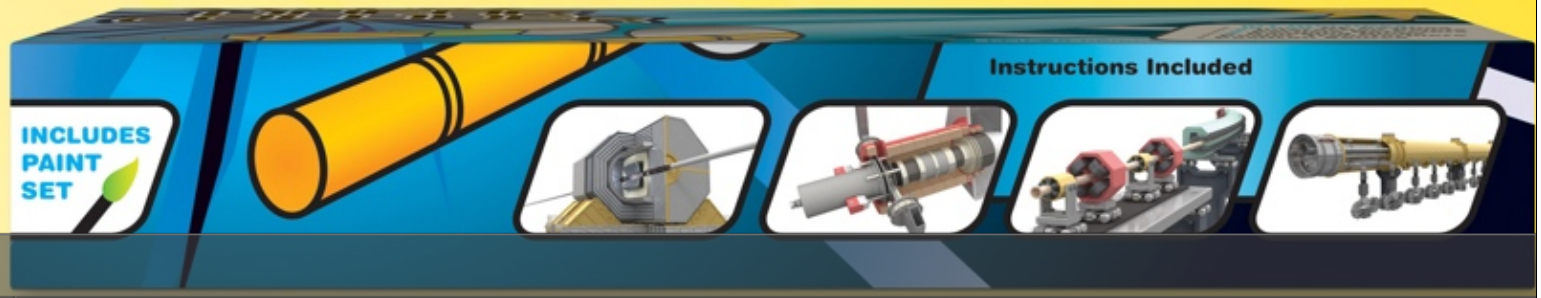
**J-Lab**



# EP facility



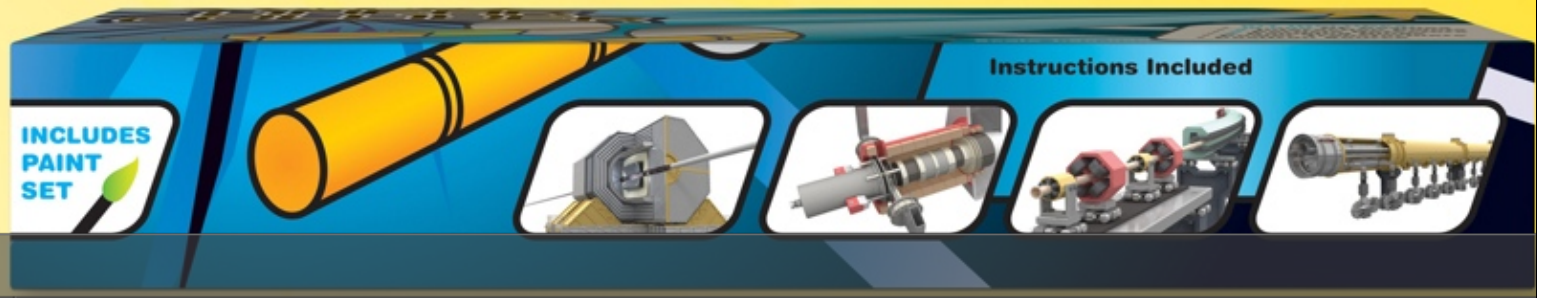
- We participate to the international collaboration (SMTF-TTC-STF) working group for the definition of specifications of the next generation EP facility
- The specifications, with small differences, are basically the same in the three regions and just need to merged into a single document
- We are actively working in collaboration with ANL, Cornell and J-Lab



# EP facility ANL



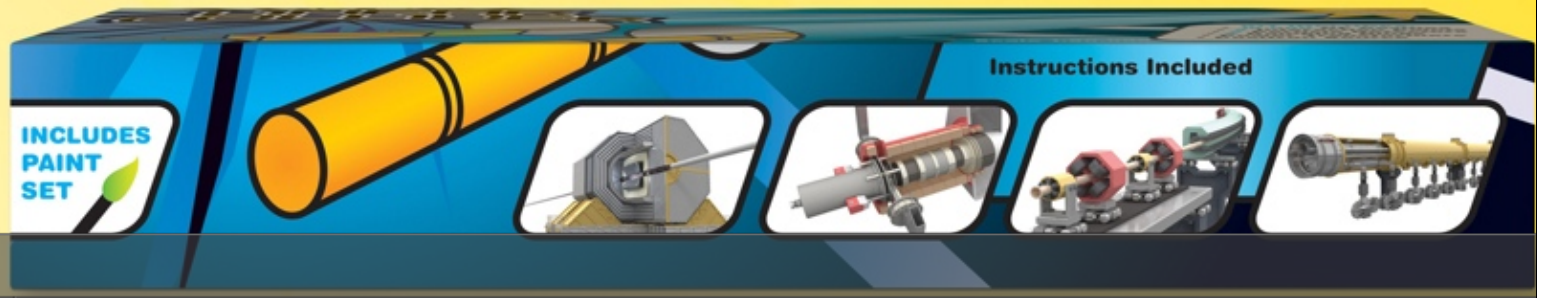
- At ANL we (A. Rowe) are commissioning the joint surface processing facility that at the moment includes the FNAL BCP facility and the ANL chemistry room.
- The ANL chemistry room will be upgraded to handle EP of ILC cavities in mid 2007
- ANL and FNAL proposed to the SMTF collaboration a plan for the fabrication (in collaboration with US industry) of a pre-industrial EP unit.



# EP facility J-Lab Cornell



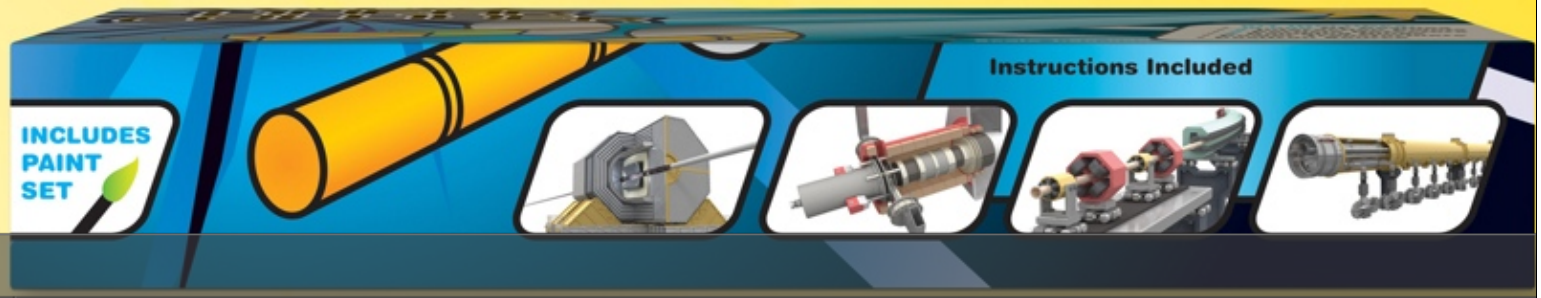
- Two MOU have been signed with Cornell and J-Lab in order to jointly perform investigations on the EP process optimization (working directly on 9-cell cavities)
- Cornell is working on Vertical EP
- J-Lab is working on the standard horizontal setup



# Connection with Industry



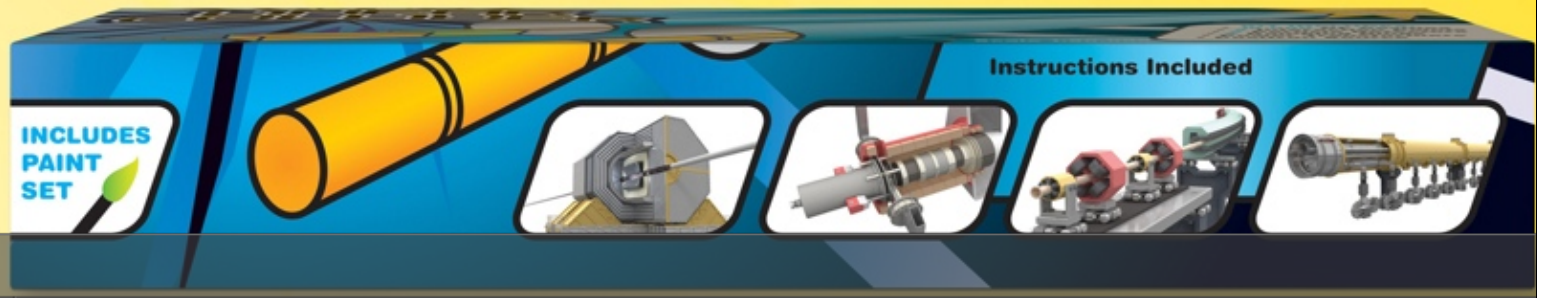
- Several contacts with industrial partners have been established:
  - Ploy-Flow Ktec (NM)
  - SPEC (CA) to be finalized
  - ABLE Electropolishing (IL)
  - Russamer Lab (PA)
  - Great Lakes Finishing Equipment (IL)
  - Panner Sales, Ryan Herco, Harringhton (IL)



# Connection with Industry



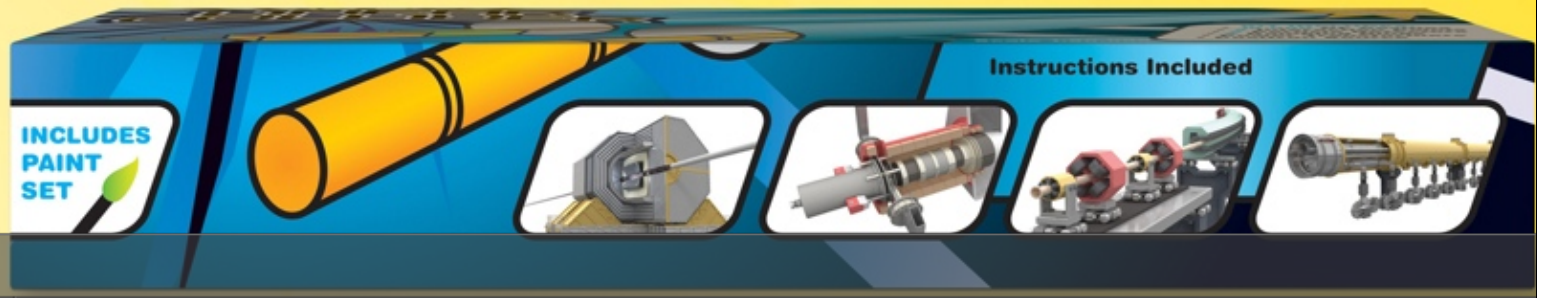
- Poly-Flow and SPEC are potential vendors that can provide a full EP unit.
- They operate in the semi-conductor industry and are specialized in plastic tools capable of handling HF processing of wafers in a confined environment. (J-Lab EP unit and HPR)
- We visited Poly-Flow in May and will propose them to perform engineering studies on a industrial EP unit able to handle a throughput of more than 100 cavities per year
- We will contact SPEC proposing the same study
- The TD procurement dept. is looking for at least an additional company



# Connection with Industry



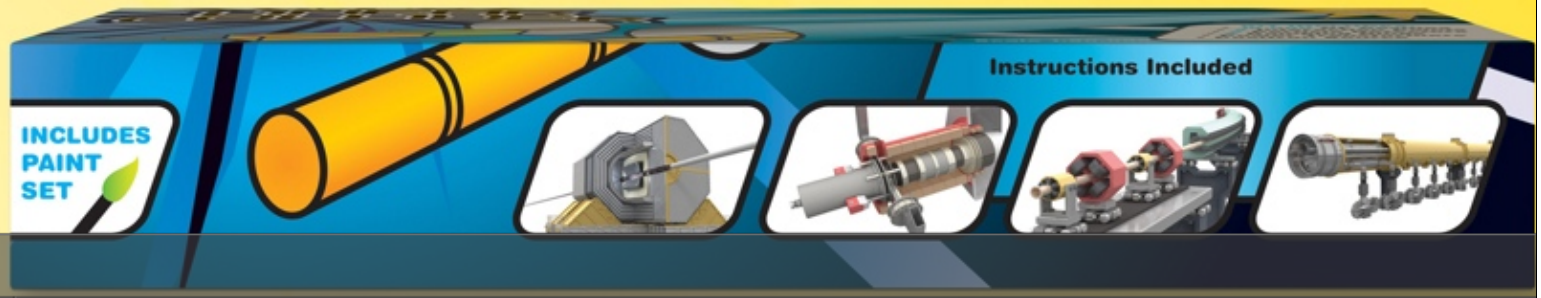
- We established a contact with ABLE Electropolishing (Chicago) trough the ILCFOA
- We sent them 6 Nb samples that they can use to check their capabilities without knowing the standard EP mix recipe
- In february we also contacted Russamer Lab. they claim to be routinely performing EP on Nb without HF. We sent them samples and received them back. The surface analysis is in progress but the surface roughness after the treatment was not satisfactory and they had problems working with large surfaces (2"x2").



# Connection with Industry



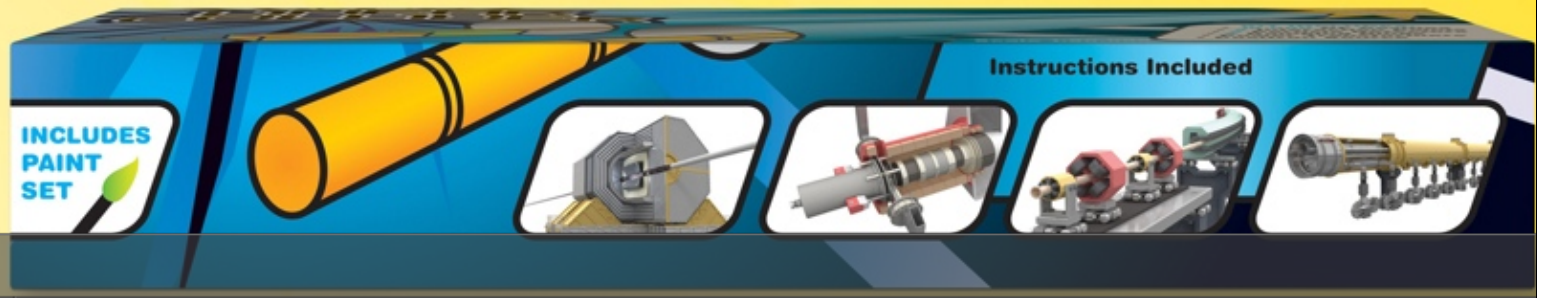
- Great lakes Finishing Equipment is a local company specialized in tumbling that has been contacted as a possible collaborator to introduce CBP at Fermilab
- Panner Sales, Ryan Herco, and Harringhton are local company that can provide services and fabrication of PTFE or PVDF parts



# CBP - C. Cooper



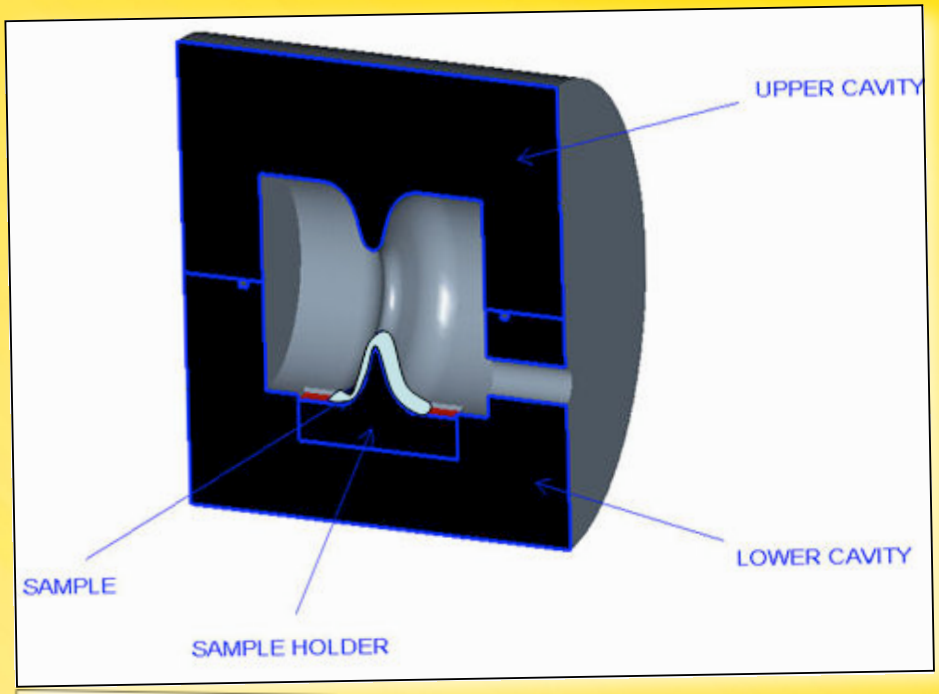
- Centrifugal Barrel Polishing (or Tumbling) was been developed both at KEK and DESY and proved to be a valid alternative to heavy chemistry.
- It is environmentally friendly
- It helps removing scratches and surface imperfections
- It was used in most of the KEK record cavities as a base processing before EP
- The biggest drawback is time, since the standard KEK recipe takes 16 hours in 4 steps



# CBP - C. Cooper

SRF Materials Group

- At FNAL we just started R&D on tumbling. A small device is being designed with the goal of identifying the proper media for the optimal surface finish results.
- In order to reduce costs and have a fast ramp up of the program we will start with the FNAL 3.9 GHz cavity shape




# Conclusions



- At Fermilab we are building a dynamic and strong team working on cavity processing and materials R&D that collaborates with the main institutions involved in SRF (but more manpower is needed to support all the activities).
- We are attaching EP from several angles with the goal of better understand the process and help defining the best specification for the industrialization of the process.
- We hope that, when the time will be mature enough, Fermilab will host processing capabilities on site.